

AIR FORCE RESEARCH IN HUMAN SENSORY FEEDBACK FOR TELEPRESENCE

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Abstract

Telepresence operations require high quality information transfer between the human master and the remotely located slave. Present Air Force research focusses on the human aspects of the information needed to complete the control/feedback loop. Work in three key areas of human sensory feedback for manipulation of objects are described. Specific projects in each key area are outlined, including research tools (hardware), planned research, and test results. Non-manipulative feedback technologies are mentioned to complete the advanced teleoperation discussions.

Introduction

The Air Force renewed its interest in remotely operated manipulator systems in 1985 with Project Forecast II. The current concept is based on the idea of a high quality teleoperated master-slave manipulator system [1]-[2]. The present program focus is centered on the feedback signals that must be generated to adequately display force information to the human operator.

The key to the successful fielding of teleoperator systems is the design and implementation of a good human-machine interface. Three human senses (touching, hearing, and seeing) hold the highest potential for effective human sensory feedback. While each sense is somewhat independent, the senses also complement each other in the human though the interdependence is not well understood. Humans use visual feedback to gather large amounts of high frequency, high resolution information about the environment. Likewise, a telepresence system can present significant quantities of information via visual displays. However, the visual system is ineffective in some environments such as heavy smoke, darkness or situations with obstructed vision. In these cases, humans often compensate with audio or tactile feedback. Audio feedback can provide information that is essentially omnidirectional and invisible. Touch and proprioceptive feedback can provide critical information regarding manipulative tasks. Tactile feedback can

supplement visual feedback and in many cases permit completion of the task without vision.

Remote Manipulation Spectrum

Prior to discussing the details of the human sensory feedback (HSF), it is important to identify the areas within the teleoperation spectrum where HSF is important. Sheridan [3] offers an excellent review of the subject and provides well-ordered definitions to each key area. Sheridan's definitions are included to provide a common point of departure:

"Telepresence is the ideal of sensing sufficient information about the teleoperator and task environment, and communicating this to the human operator in a sufficiently natural way, that the operator feels physically at the remote site."

"Teleoperation is the extension of a person's sensing and manipulation capability to a remote location. A teleoperator includes at the minimum artificial sensors, arms and hands, a vehicle for carrying these, and communication channels to and from the human operator. The term "teleoperation" refers most commonly to direct and continuous human control of the teleoperator, but can also be used generally to encompass "telerobotics" (see below) as well."

"Teleroobotics is a form of teleoperation in which a human operator

acts as a supervisor, intermittently communicating to a computer about goals, constraints, plans, contingencies, assumptions, suggestions, and orders relative to a limited task, getting back information about accomplishments, difficulties, concerns, and, as requested, raw sensory data-- while the subordinate telerobot executes the task based on information received from the human operator plus its own artificial sensing and intelligence."

"Supervisory Control in the present context is mostly synonymous with telerobotics, referring to the analogy of a human supervisor directing and monitoring the activities of a human subordinate. The term "supervisory control" is used commonly to refer to human supervision of any semi-autonomous system (including an aircraft, a chemical or power plant, etc.), while 'telerobot' commonly refers to a device having arms for manipulating or processing discrete objects in its environment."

"Robotics is the science and art of performing, by means of an automatic apparatus or device, functions ordinarily ascribed to human beings, or operating with what appears to be almost human intelligence (adapted from Webster's Third International Dictionary)."

As can be seen in Figure 1, the level of human operator involvement varies with each key area.

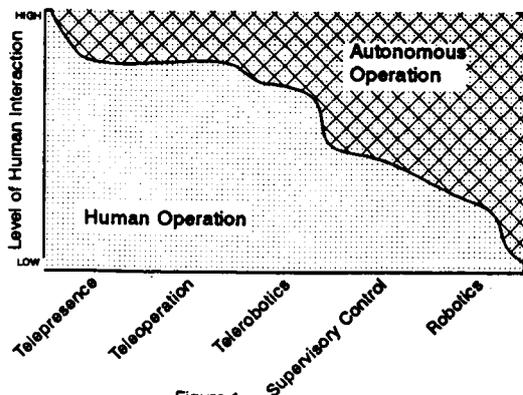


Figure 1

Armstrong Laboratory Research

Human Sensory Feedback Research at the Armstrong Laboratory's Crew Systems directorate is centered in three areas of the force feedback domain:

Coarse Positioning - Movement produced by large scale motion associated with the human arm. Coarse manipulation implies movement to position a dexterous end effector in the proper orientation to perform work via fine manipulation.

Fine Manipulation - Small scale motion associated with the human hand. Fine manipulation is the performance of tasks using highly dexterous end effectors.

Tactile Feedback - Determine the role of tactile feedback from the remote system to the human operator. Identify and investigate technologies important to providing high fidelity tactile feedback to human operators.

Coarse Positioning Research

Current coarse positioning investigations are evaluating the impact of exoskeletal systems on human performance. The method is to measure human performance using an instrumented "peg-in-the-hole" task board based on Fitts' Law [4][5]. The unencumbered operator executes a test sequence to obtain a baseline of task performance. The operator then dons a non-force-reflecting (NFR) exoskeleton and re-executes the test sequence. The difference yields an indicator of the restriction of the exoskeleton on the human's task performance. Results of the initial study show a 32 to 41 percent reduction in task performance. This reduction in task performance is due solely to the interference caused by the NFR exoskeleton.

Follow-on testing will evaluate task performance as the human operator uses the exoskeleton to teleoperate a slave robot. The result will be a system-dependent indicator of the impact of the total master-slave system on the task performance. The preliminary testing was done with a NFR exoskeleton. The final sequence in this phase will be completed with a NFR exoskeleton. This NFR exoskele-

ton encumbrance test forms the basis for subsequent testing using the force reflecting exoskeleton described below.

For the past two years, Odetics, Inc., has been developing a Force REFlecting EXoskeleton (FREFLEX) to evaluate the impact on task performance of force reflection with a non-constraining seven-degree-of-freedom force-reflecting exoskeleton. Design of the cable-driven system is discussed in [6].

A similar series of test sequences will be conducted using the FREFLEX. The encumbrance of the FREFLEX will be measured in the NFR mode as before. Once the passive baseline is determined, a series of force reflecting experiments will be conducted to evaluate several parameters such as gravity and friction compensation, feedforward and feedback control algorithms, and modified kinematic and dynamic parameters. The expected result is an increased understanding of each of the factors that impact the human operator in a complex telepresence system. The end goal is to develop design parameter guidelines that are based on knowledge of the human characteristics in the telepresence system.

A second interest area in coarse positioning is to quantify kinematic and dynamic limitations placed on the operator by the exoskeleton system. Research in this area is centered on the WATSMART™ [14], a three dimensional motion analysis system. The approach is to measure the operator's kinematic and dynamic parameters with and without the exoskeleton. The objective is to examine the joint-by-joint kinematic and dynamic encumbrances placed on the operator by the exoskeleton. The resultant data is expected to lead to human-based parametric design guidelines for exoskeletons.

The WATSMART™ data will also be used to establish velocity and acceleration profiles of each joint. In addition to evaluating the encumbrance effects, these velocity and acceleration profiles are necessary to develop mechanical performance parameters of motors and actuators for future exoskeleton devices.

Fine Manipulation Research

Fine manipulation research at the Armstrong Laboratory is centered on the pair of dexterous hands designed by Jacobson at the University of Utah [7]. Initial plans were to combine the robotic hands with the robotic arms to form a slave system for telepresence research. Funding reductions have prevented arm-hand integration but theoretical research has continued. Whalen [8] developed a basis for planar grasping as a foundation for dexterous robotic hands. Future work will be directed toward understanding the relationship of each digit of the robotic hand.

A key component to successful fine manipulation via telepresence is the development of kinematic and dynamic models between the slave hand, the operator's hand-master controller, and the operator's hand. Initial kinematic mapping from the slave hand to the master hand controller to the human operator's hand has been completed [9]. Force feedback for hand-master controllers will require innovative actuation schemes. Initial thoughts on hand master controllers with feedback indicate requirements for high speed, lightweight actuators with high power densities and approximately linear responses. Current plans call for feedback signals for the actuators to be derived from tendon tension signals on the dexterous hands. Long term objectives will combine the hand master control loop with the slave hand control loop to produce a force feedback capability in fine manipulation. Auxiliary force information from tactile sensors on the hands may also be integrated into the overall feedback scheme to provide even more stable control.

Tactile Feedback Research

The third, but much less understood, area of force feedback is tactile feedback. Tactile feedback plays a critical role in human performance. Armstrong Laboratory work in this area has two key thrusts: (1) The addition of sensors to one of the dexterous hands (2) the development of small lightweight tactile stimulators.

A Phase II Small Business Innovation

Research (SBIR) project will yield a sensorized robotic hand in FY93. The sensor suite includes palmar sensors as well as sensors on the back of the robotic fingers. Additional sensor research is ongoing at the Air Force Institute of Technology. Nering [10] is developing a slip sensor using resistive paint and artificial neural networks. Other AFIT researchers [11][12] have explored the use of polyvinylidene fluoride film to fabricate high-density contact position and force sensors on silicon substrate.

The second component of the tactile feedback subsystem is the tactile stimulator for the human operator's hand. While a specific technology has not been selected, present work focusses on Shape Memory Alloy (SMA). The current device is a five-by-six (30-element) array using SMA actuators for stimulator pins[13].

Psychophysical perception testing on human subjects is planned to evaluate the SMA applicability to tactile stimulator technology. Follow-on investigations will explore operator capability to detect active and static patterns and to identify dynamic patterns. Long term plans call for the integration of the robotic tactile sensors with the operator tactile stimulators to achieve a closed loop feedback subsystem in the tactile domain.

Conclusion:

Armstrong Laboratory research in human-in-the-loop controlled robots is focusing in three key areas. Coarse positioning, using force-reflecting exoskeletons, is the key element in positioning the robotic end effector to do work. Once the coarse positioning subsystem has the manipulator in place, the fine manipulation task will be performed by highly dexterous robotic hands. Force feedback to the human operator via a force-reflecting hand master is planned. Tactile feedback research centers on shape memory alloy technology for tactile stimulators. The stimulators will be combined with the robotic tactile sensor suites to yield a complete tactile subsystem.

Long term plans call for integration of the three manipulation areas into

a single manipulation system with intuitive force feedback. It is anticipated that video feedback subsystems and audio subsystems will have off-the-shelf availability when the manipulation matures sufficiently for total system integration.

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